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Improving animal health and welfare in the transition of livestock farming systems: towards social acceptability and sustainability

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Abstract

The need to integrate more clearly societal expectations on livestock farming has led the authors of this article to consider that livestock farming systems must be redesigned to position health and welfare at the heart of their objectives. This article proposes a vision of the advances in knowledge required at different scales to contribute to this transformation. After defining health and welfare of animals, the article emphasizes the need to consider health in a broader perspective, to deepen the question of positive emotional experiences regarding welfare, and raises the question of how to assess these two elements on farms. The positive interactions between health and welfare are presented. Some possible tensions between them are also discussed, in particular when improving welfare by providing a more stimulating and richer environment such as access to outdoor increases the risk of infectious diseases. Jointly improving health and welfare of animals poses a number of questions at various scales, from the animal level to the production chain. At the animal level, the authors highlight the need to explore: the long-term links between better welfare and physiological balance, the role of microbiota, the psycho-neuro-endocrine mechanisms linking positive mental state and health, and the trade-off between the physiological functions of production, reproduction and immunity. At the farm level, in addition to studying the relationships at the group level between welfare, health and production, the paper supports the idea of co-constructing innovative systems with breeders, as
well as analyzing the cost, acceptability and impact of improved systems on their
working conditions and well-being. At the production chain or territory levels, various
questions are raised. These include: studying the best strategies to improve animal
health and welfare while preserving economic viability, the labelling of products and
the consumers' willingness to pay, the consequences of heterogeneity in animal traits
on the processing of animal products, and the spatial distribution of livestock farming
and the organization of the production and value chain. At the level of the citizen and
customer, one of the challenges is to better inter-relate sanitary and health
perspectives on the one hand, and welfare concerns on the other hand. There is also
a need to improve citizens' knowledge on livestock farming, and to develop more
intense and constructive exchanges between breeders, the livestock industry and
citizens. These difficult issues plead for interdisciplinary and transdisciplinary research
involving various scientific disciplines and the different stakeholders, including public
policy makers through participatory research.

**Keywords**
Health, welfare, animal, livestock farming systems, production chain, value chain,
territory, society

**Implications**
This collective reflection was performed to push interdisciplinary research in order to
improve both the health and welfare of farm animals. The goal is to place health and
welfare of the animals at the core of the livestock farming systems, and to favour
transitions in the livestock farming systems and sectors. These goals are key elements
in the acceptability of animal farming for the citizen and important aspects for the
sustainability of animal farming in the coming years. An interdisciplinary research programme was launched and funded by INRAE on the basis of this work.

**Introduction**

Livestock farming is currently the subject of increasing concern by society and citizens. Questions are being raised about the environmental footprint of livestock production as well as about our stewardship of the animals under our care and their resulting well-being. These questions are given urgency by the twin challenges of ensuring global food security and dealing with the climate change. FAO (Food and Agriculture Organization of the United Nations, 2006) drew attention on the land used for livestock and the competition with crops to feed humans, on the contribution of livestock to global warming, water depletion and pollution, and its impact on biodiversity. In France, according to Delanoue and Roguet (2015), the primary societal concerns regarding livestock farming relate to the so-called intensive and industrial farming (i.e. high productivity, high animal density, high drug use and indoor breeding). The main worries with these systems are about the welfare of animals, their health and the sanitary crises. Underpinning the concerns related to animal health and welfare, there is a societal demand for a healthy diet that will not lead to adverse effects on human health and even provide some benefits. Animal safety is directly related to the livestock farming systems, as illustrated by sanitary crises such as those related to influenza (Sidik, 2023). Animal health management such as the large use of antimicrobials also contributes to antimicrobial resistance dissemination, which is a major threat for the coming decades. In a systematic review on public perceptions regarding production diseases associated with farm animal welfare, Clark et al (2016) mention that citizens
have a holistic view of welfare and health of animals, and they consider that what is bad for animals is also bad for consumers. Furthermore, efforts to protect the health of animals at the expense of more open livestock farming systems (e.g. closed systems to limit disease exposure of the animals) is not supported by citizens. Clark et al (2016) indicate that more welfare friendly systems are associated with additional benefits for the consumer (quality, safety). However, at the same time, welfare is not a priority when shopping, with barriers to consumption such as price, availability and perceived personal influence remaining. The expectations of the society concerning the health and welfare of animals are shared by breeders. The latter are concerned by the welfare of their animals and try to give them the best life from their point of view (Buddle et al., 2021). Indeed, without any constraints and regulations, breeders may innovate in this field, as in the case of dam-rearing systems (Vaarst et al., 2020) or by the use of alternative practices in health management (Hellec et al., 2021). This invites us to consider animal health through a global “one health” approach. Also, under the treaty on the functioning of the European Union (Article 13 of Lisbon Treaty), animals are recognized as sentient beings and consequently the EU and the Member States must pay due regard to the welfare requirements of animals when preparing and implementing EU policies in agriculture or internal markets, for examples.

Given the societal loss of trust towards livestock farming, it must change quite strongly in the coming years to regain respect for its stewardship of the animals involved. Now more than ever, it seems urgent and important to consider animal health and animal welfare in the design of future livestock farming systems. In this transformation process, we consider that livestock farming systems must be completely redesigned by all stakeholders in the sector to position health and welfare at the heart of their
objectives, as well as the well-being of breeders. Some authors even call for a real paradigm shift, and propose a new conceptual framework called "circular welfare economy" involving a complete overhaul of the agricultural system, the economy and even society as a whole (Bracke et al., 2023). More concretely, synergies and tensions with the other dimensions of performance must be determined in order to guide choices towards the most multi-performing systems. Health and welfare need to be taken into account simultaneously, because they are tightly linked and interact with each other, not always in a positive way, and because they are critical points in the acceptability of livestock farming systems by the citizens and consumers. This raises the question of knowing under what conditions it will be possible to jointly improve the health and welfare of the animals, and to consider them as fully-fledged components of the sustainability of production systems. The purpose of the present paper is to address this question and to propose a conceptual framework in which the corresponding research questions are situated.

The process of innovation to achieve improved health and welfare of the animals within sustainable systems can take an incremental and progressive path, made of small steps, to optimize the system without making it deviate from its trend, with possible forms of substitution of one element by another. Alternatively, it can make a break and fundamentally modify the livestock farming system in a more disruptive way, even through a progressive path. Both paths can be useful, though some voices claim that no significant improvement can be expected from small steps changes to intensive livestock farming systems (Leterrier et al., 2022; Bracke et al., 2023). There is already knowledge and experience in the domains of health and welfare of farmed animals, and the interactions between health and welfare at animal level have been studied for
some time (Broom, 2007). However, simultaneously taking into account health and welfare as the main objective in designing new livestock farming systems requires multiple expertises. In this paper, we propose a research strategy centered on this goal. We first define animal health and animal welfare, and the research questions raised to evaluate them on farms. Then we address the questions linked to the interactions between health and welfare of animals, both positive and negative. Finally, we consider how the transformation of livestock farming activities toward health and welfare scales up to research questions at the farm level, at the industry and territory levels, and ultimately on the society’s view of livestock farming and its evolution.

What do we mean by animal health and animal welfare?

What does animal health refer to?

Historical perspective from Human medicine

Western medicine has been dominated by two conceptions of disease, termed “ontological” and “physiological”, both considering health as the absence of disease. In the ontological conception, disease is seen as a distinct entity, exogenous to the organism, such as a spirit, a parasite, a germ, a poison, which “penetrates” the individual to cause disturbances (symptoms). The treatment and the cure (the return to health) consist in eliminating, expelling this foreign “element”. “Disease enters and leaves humans, as if through the door” (Canguilhem, 2005). In primitive and archaic societies, the supernatural, represented by gods, demons, wizards, was frequently invoked, especially during epidemics. At the end of the 19th century, the emergence
of modern microbiology and infectiology (L. Pasteur, R. Koch, etc.) brought scientific evidence to support this conception.

In the physiological or dynamic conception, the disease reflects an imbalance of the organism, a disturbance of its "internal environment", of its anatomical and functional integrity. This conception is therefore centered on the “sick person”, and not on the “disease, external and distinct element”. Illness and health are a continuum and not strictly independent (Conti, 2018). The treatment (and therefore the restoration of health) aims to return to harmony, the balance of “humors” which explains the systematic use of purgatives, emetics, bloodletting in ancient times. Identified since Greco-Roman antiquity (Hippocrates, Galen, etc.), this conception, transmitted by Arab medicine from the Middle Ages, has been enriched over the centuries. At the end of the 19th century, the advent of experimental physiology (C. Bernard, R. Virchow, etc.) brought scientific and explanatory elements to support this conception. In Oriental or Asian medicine (traditional Chinese; Indian called Ayurvedic - from āyur = longevity and veda = knowledge -) the notions of illness and health can be compared to the physiological conception (Mazars, 1994; Saylor, 2004). These two complementary conceptions (ontological and physiological) have largely contributed and continue to contribute to nourishing biomedical research.

In human medicine, in addition to the biological components of health, the “holistic theory” of health gives a preponderant part to a “subjective” component; without denying the biological aspects, this approach considers that health depends essentially on the perception of the subject, and therefore on socio-cultural values and references that vary in space, time, and according to individuals. The definition of health
established in 1946 by the World Health Organization goes beyond the absence of
disease and traditional, strictly physical and biological criteria, and displays a positive
and plural dimension in nature (physical and mental integrity, well-being) and scale
(individual and population): "Health is a state of complete physical, mental and social
well-being, and not merely the absence of disease or infirmity" (World Health
Organization, 2017).

Health and disease of farm animals

The two historical approaches to health mentioned previously echo two important
dimensions of the health of farm animals. The first one is the exposure to external,
infectious, and toxic agents, which are the main causes of transmissible diseases,
some of which are zoonotic and may involve wildlife (for example African swine fever,
bovine tuberculosis, avian influenza, brucellosis). This includes the transmission,
asymptomatic in animals, of pathogenic agents to humans (eg salmonella, hepatitis E
virus, trichina). The second dimension refers to the physiological imbalances, that can
be increased by deficient rearing conditions of animals highly selected for production
potential in highly intensive livestock farming systems. These disorders can result
(Calavas and Rosner, 1997) in excess morbidity and mortality thus altering longevity
(Rostellato et al., 2022), sudden drops in performance (lack of robustness), and are
often linked to physiological imbalance or common metabolic or infectious diseases
(for example diarrhea in piglets at weaning, mortality of one-day chicks, mastitis in
dairy cows, bronchopneumonia in young cattle).
The philosophical approaches developed for human health emphasize the importance of well-being, subjectivity, socio-cultural values and contexts to characterize the health status or the presence of disease, particularly for benign or chronic diseases. Perhaps because these values and contexts were not readily accessible in animals – one cannot ask an animal how it feels – they have not traditionally featured in the characterization of animal health status. The perception of health of farm animals can be quite different depending on whether it is made by the breeder, the veterinarian, or the citizen/consumer (Mahon et al., 2021). Taking the health of the udder of dairy cows as an example, different breeders do not necessarily consider the same criteria to determine that a cow has a sub-clinical infection, the veterinarian will tend to retain objective indicators (somatic cell count) based on a consensus standard of the profession, and the consumer will have the expectation that the cow has not undergone any treatment that could alter the quality of the milk. In broiler flocks as another example, different breeders may consider different levels of mortality to be normal, and the level of productivity achieved is an indicator of health for some of them.

Based on the World Health Organisation (WHO) definition of health, and also placing animal health in the perspective of the supply of animal products that are safe for human health, it seems important to consider an integrated ("holistic") approach to farm animal health, to consider the two components of health (risk of exposure to pathogens and physiological balance) and to focus on the best balance to be found in livestock farming practices. Furthermore, it is important to consider both the individual dimension of animal health and the herd level. Mental state of the animals has not until now been considered for farm animals, apart from abnormal behaviours generally observed under intensive farming conditions (for example feather pecking, bites,
stereotypies, self-mutilation). In connection with the animal welfare approach, it would also seem useful to take an interest in the concept of “mental states” of production animals.

Given the variety of livestock farming systems and species raised, and the diversity of points of view (breeder, veterinarian, citizens), it seems illusory to search for a generic and universal definition of animal health. In agreement with van der Linden and Schermer (2022), a pragmatic vision seems appropriate to make progress on the issue of the health of farmed animals. This vision must nevertheless be clearly explained by indicating which points of view are considered (breeder, veterinarian, citizen), which dimensions are taken into account (for example risk with respect to major regulated diseases, impact on the career of the animal (i.e. longevity)). Further, any definition should also be clearly framed in terms of the operational context in which it is to be used, such as research, health monitoring, etc.

**Practical assessment of animal health**

The integrated conception of animal health presented above is important if we are to move beyond a narrow focus on the presence or absence of specific diseases. However, this raises research questions with respect to measuring the health of an animal and of a herd in farming conditions. The choice of parameters and their combinations needs to be considered and evaluated, for the different animal species and for different periods of life of the animals. The relationships and boundaries between health and disease should be explored, with the concept that healthy and sick are (opposed) points on a continuum. Accepting that health status is a continuum offers
the prospect of defining objective, nuanced and operational criteria on which to build improved diagnostic and intervention tools, tuned according to the domains and biological functions considered (metabolism, reproduction, robustness, longevity, etc). Significant opportunities to achieve this are offered by the advent of on-farm monitoring technologies, and more recently the “Internet of Things” (Tuyttens et al., 2022). These provide high-frequency repeated measures allowing health status of animals to be monitored and quantified on a continuous scale (Højsgaard and Friggens, 2010).

It would also be useful to consider how to define health at the level of the lifespan of the animal (or key stages of its career). Studies are emerging that make use of the repeated measures that are increasingly available, including the monitoring of the maintenance of good health or the capacity of the animals to recover quickly after a disease (Vaarst and Alrøe, 2012).

These research questions focused on evaluating the health status of the animal should go hand-in-hand with research on the different perceptions of what health is for different stakeholders, which can be extremely contrasted depending on who they are: breeders, veterinarians, or citizens. These perceptions can also vary within the same social group, for example between breeders in conventional and organic livestock farming. This implies the need for dialogue between these actors and the co-construction of consensus in order to move towards approaches that suit all actors.

**What does animal welfare refer to?**
The relationship between humans and animals, both domestic and wild, is multi-millennial. In fact, the mutual dependence between human societies and certain animal populations have been such that animals have gradually changed in their physiology and behaviour through the process of domestication (e.g., Price, 1984; Mignon-Grasteau et al., 2005; Larson and Burger, 2013; Ahmad et al., 2020). In the same way, the presence of animals has been intimately involved in the development of human cultures to the point of shaping them (Patou-Mathis, 2009). The process of domestication is far from being reduced to its purely economic aspects, even in current livestock farming systems, but also includes symbolic and affective dimensions. This tension at the heart of the human-animal relationship between a utilitarian perspective of exploitation and a more affective feeling has long exercised philosophers. Their most significant concerns about the human-animal relationship led to efforts to elucidate the ethical dimension of farming animals.

Philosophical thought has particularly focused on the goal of limiting suffering (where suffering is defined as experiencing pain, affliction or distress: Anonymous, 1971) but beyond it, tended more widely to relate this concern to the presence of sentience in animals in common with humans. During the 18th century, Rousseau (1754) was particularly important in putting very clearly in light this ethical basis: “It appears, in fact, that if I am bound to do no injury to my fellow-creatures, this is less because they are rational than because they are sentient beings: and this quality, being common to men and beasts, ought to entitle the latter at least to the privilege of not being wantonly ill-treated by the former.” Along these lines but more restrictively, Bentham (1789)
claimed about animals in a very famous sentence: "The question is not: Can they reason? Or: Can they talk? but: Can they suffer? " More recently, the scientific results of investigations into animal skills in terms of sentience and awareness or consciousness (see below) confirm the validity of this ethical concern and increase its scope by extending it from the negative aspect (minimizing pain / suffering) to the inclusion of a positive aspect (maximization of pleasures) of mental states. For example, Larrère (2007) states: "Sentience, this capacity to feel (and express) mental states like pain and pleasure, suffering and satisfaction, common to men and animals, precedes in the first what distinguishes them from the second (speech, reason, symbolization, etc.)."

At the European level, the principle of sentient beings was enshrined in 2009 in Article 13 of the Treaty on the Functioning of the European Union (2016): “the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals”. Animal welfare has become a political issue, with both the development of animal protection associations and the appropriation of this issue by legislators in the Member States." The sentient nature of animals was already recognized in French law by the addition of positive and preventive obligations of animal suffering to the texts already in force, being the fruit of the law of 10 July 1976 on the protection of nature which recognized in its article 9 that: “… every animal being a sentient being must be placed by its owner in conditions compatible with the biological imperatives of his species.” It was finally introduced in the Civil Code: "Animals are living beings endowed with sentience." (Law of 16 February 2015, Article 515-14), opening the way towards an evolution of the legal status of animals.
Today, animal welfare has become one of the objectives of the European Union: “In formulating and implementing the Union’s agriculture, fisheries, transport, internal market, research and technological development and space policies, the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals, while respecting the legislative or administrative provisions and customs of the Member States relating in particular to religious rites, cultural traditions and regional heritage.” (Article 13 of the Treaty on the Functioning of the European Union, which has consolidated in one single text all the founding Treaties; the Treaty of Lisbon: European Union, 2007). Indeed, all the current legislation on animal protection and welfare was elaborated at the level of the European Union and then implemented into national legislation in the Member States.

Concern for welfare can however take several forms: either reducing itself to minimizing as much as possible the supposed causes of suffering or discomfort, or seeking to promote the expression of behaviours specific to the species, by providing in their environment the means for this purpose. Nevertheless, some authors still argue that the actual benefit of animals’ ability to exercise “natural behaviour” on its welfare needs to be evidenced (Dawkins, 2023). The latter perspective is one of ethics of integrity (Bovenkerk et al., 2002) that can go so far as to recommend the return - within the limits of what is possible after the impact of the domestication process - to the conditions of a natural/outdoor environment. This even extends to the point of reintroducing the risks associated with it (for example the health risk and the presence of predators in semi-open flocks). Thus, the possibility of contradictions between the concern for animal welfare and provision of a natural environment have to be addressed. In the search for improved welfare, a more moderate vision consists of
respecting certain environmental conditions allowing the expression of the behaviours specific to the species.

In the field of animal farming, the highlighting by Harrison (1964) of the prevailing conditions of intensive livestock production in Great Britain followed by the establishment of the Brambell Committee (1965) marked a turning point in way that citizens considered the animals they share or use for their own purposes. The mission of this committee was to make recommendations and propose minimum welfare standards that meet the basic needs of animals under intensive livestock farming conditions. In 1965, the committee produced a report rightly considered to be the foundation of reflections and approaches relating to the welfare of farmed animals in Europe (1965). The first contribution of this report is an often-overlooked definition (Chapter 4, paragraph 25): “Welfare is a wide term that embraces both the physical and mental well-being of the animal. Any attempt to evaluate welfare therefore must take into account the scientific evidence available concerning the feelings of animals that can be derived from their structure and functions and also from their behaviour.” This definition already referred to the existence of mental states in animals, a recurring point of controversy between stakeholders (Fernandes et al., 2019). It can also be noted that this definition considers the animal as a sensitive and conscious individual. Animal sentience includes the ability to perceive sensations through sight, hearing, smell, taste and touch, as well as the ability to feel emotions, bearing in mind that an animal's emotional capacities depend above all on its sensory world (Boissy et al, 2007). Consciousness (Le Neindre et al, 2017) relates to the ability of the animal to reflect on its actions, to have a subjective or phenomenal experience of its environment, its own body and/or its own knowledge; it enables it to adapt to a
changing and often unpredictable environment. The definition distinguishes ‘welfare’ as a concept from ‘well-being’ that describes the state of the individual animal. Further scientific advances in the knowledge about sentience (Le Neindre, 2009) and consciousness (Le Neindre et al., 2017) of animals have reinforced these concepts, now widely accepted, both by national (Agence nationale de sécurité sanitaire de l’alimentation de l’environnement et du travail, 2018; Mormede et al., 2018) and international agencies (World Organisation for Animal Health, 2022).

Current definition of welfare

Thus, the latest definition of ‘animal welfare’ by the World Organisation for Animal Health (WOAH) thus states “Animal welfare means the physical and mental state of an animal in relation to the conditions in which it lives and dies” (World Organisation for Animal Health, 2022). This definition is completed by the statement that “While animal welfare refers to the state of the animal, the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment.” In France, according to the opinion of the French Agency for Food, Environmental and Occupational Health & Safety (Agence nationale de sécurité sanitaire de l'alimentation de l'environnement et du travail, 2018), "an animal's well-being is the positive mental and physical state linked to the satisfaction of its physiological and behavioural needs, as well as its expectations. This state varies according to the perception of the situation by the animal." This definition reinforces the importance of the mental dimension of the feeling of the animal considered in its environment. Thus, good health, a satisfactory level of production and an absence of stress are not enough to ensure the well-being of the animal. We must also worry about
what the animal feels, namely its unpleasant subjective perceptions (fear, pain and
suffering) but also its positive emotions (satisfaction, pleasure, etc.). This means that
improving the welfare of animals should no longer be limited to reducing their suffering
and stress, but also to developing living conditions that give them positive emotional
experiences.

Practical assessment of animal welfare: from the individual to the group

The framework that historically underlies the practical approach to animal welfare,
known as the "Five freedoms", was first published by FAWC in 1979, then in 2009 in
its current form (Animal Welfare Committee, 2009). This statement includes, in general
terms, indications of what human beings must offer animals to ensure their welfare:

- Lack of hunger and thirst by having free access to safe water and food to
  maintain a good level of health and vigour;
- No discomfort through proper environment, including a comfortable shelter and
  rest area;
- Absence of pain, injury and illness through preventive measures or rapid
  diagnosis, followed by appropriate treatment;
- Freedom of expression of normal behaviour thanks to sufficient space, adapted
  facilities and the company of other congeners;
- Absence of fear and distress by ensuring living conditions and treatment of
  animals avoiding mental suffering.

The current definitions of welfare reported above are suitable for the animal as an
individual, but the practical assessment is often in the context of groups of animals
both at the farm and at the slaughterhouse for production animals. The first step is to assess the state of welfare at the level of the individual in its environment. A second step is the integration of individual data at the group level (e.g. the context of the farm).

The assessment of welfare at the individual level is based on the assessments of the physiological and health status of the animal, as well as its behaviour and its reactivity to humans (animal-based measures). Assessing welfare also implies to take into account the characteristics of the environment as risk factors to animal welfare and levers to improve it (Whay, 2007). An important question is how to move from acquired understanding by studying the welfare of individuals to assessing the overall welfare of a group. Several farm animal welfare assurance schemes have been developed and used on a large scale. The approach adopted in the EU-funded Welfare Quality® project illustrates the degree of complexity of an evaluation tool and the question of an overall evaluation (Veissier et al., 2010). The initial protocols were built for a limited number of production species (pork, laying hens and broilers for fattening, cattle other than calves) as the beginning of a complete evaluation process of the livestock farming systems shared at the European scale and with a decision-making objective in actions to improve welfare. At the European level, these first protocols (Welfare Quality®, 2009a, 2009b and 2009c) constitute a reference system, from which new protocols have been developed, with improvements in procedures and adjustments to other species (goats, horses, sheep, turkeys), which have for example also been developed in the AWIN project (AWIN, 2015a, 2015b, 2015c and 2015d). Numerous simplified tools have been derived from theses protocols to make evaluations of welfare easier and available to all actors, including the breeders (e.g. BEEP for pigs, EBENE for...
poultry and rabbits, BOVIWEL for cattle, ‘cheval bien-être’ for horses), and the advent of on-farm monitoring technologies opens new perspectives.

**To which extent are animal health and animal welfare connected?**

There are conceptual links between animal health and animal welfare, based on the definitions seen previously. The concept of "mental well-being" in connection with positive mental states, is an integral part of the WHO definition of health that includes the mental and social well-being (World Health Organization, 2017). At the same time, the most recent definitions of welfare by Agence nationale de sécurité sanitaire de l’alimentation de l’environnement et du travail (Anses) (2018) or the WOAH (2022), are based, among other things, on a need to achieve a positive physical state (thus a good health). Apart from these links, there are other connections between health and welfare.

**Causal Links between health and welfare**

A causal link is observed mostly, and described first, in one direction, i.e., the adverse effects of altered animal welfare on disease susceptibility, in particular via a deterioration in immune function, to the point that disease susceptibility and immune function are used as indicators of welfare (Broom and Kirkden, 2004). Advances in the field of psychoneuroimmunology shed light at a functional level on the link between the hypothalamus, the reticular formation and the immune response, suggesting that the immune response is partially under the control of psychological processes (Zachariae,
Conversely, the immune system exerts control over the central nervous system, primarily through the cytokine pathway (Dantzer, 2018). Andrew Fraser and Donald Broom, two pioneers in the field of farm animal welfare, were among the first to address this link between welfare, animal behaviour and health, particularly in their book *Farm Animal Behaviour and Welfare* (first published in 1974; Fraser and Broom, 1997). They rely on some observations suggesting that certain animal husbandry practices affect both animal welfare and disease incidence. For example, they cite a 1974 study that reported an increase in chronic infections in livestock farming systems as they were intensified. And intensification of production systems is very often associated with higher antimicrobial use. A recent review by Rodrigues da Costa and Diana (2022) suggests that, in farm animals, better welfare often leads to lower antimicrobial use, as was hypothesized, and that, generally, poor welfare is associated with higher antimicrobial use. Diseases linked to physiological imbalances, with or without an infectious component, are very dependent on husbandry practices and, in this sense, are possibly in strong interaction with the state of animal welfare.

Data on the effects of improved welfare on disease resistance are less abundant, this is probably at least partly due to the fact that research in the field of positive welfare started late (Boissy et al., 2007). Results from Lutgendorf (2001) and Sachser (2001), as cited by Broom (Dahlem Workshop, 2001) indicate that improved welfare status, aided by social support from conspecifics, reduces the risk of disease. There is indeed some evidence that improved welfare can be a means to improve immune function, without the use of drug inputs, and a means to improve immunocompetence, including response to treatment, when needed, and to vaccines or infection. However, the
relationships between welfare, immunity and disease resistance are more complex than they appear (Berghman, 2016).

Consequently, there seems to be no simple relationship between measures of immune activity and welfare (Boissy et al., 2007). As stated by Dawkins (2019): "Research is urgently needed into the relationship between animal welfare, immunity, gut microbiota and disease and we are not yet in a position to claim that improving welfare will improve resistance to disease. ‘Boosting’ the immune system is not straightforward and an interdisciplinary approach is needed”.

Health and welfare may respond differently to livestock farming practices

Changes in husbandry practices associated with a change in environmental living conditions, like access to outdoors, have profound, but complex and ambiguous, effects on animal health and welfare, and on their interactions. Typically, animals can be given access to outdoors to increase their welfare, but it may have many detrimental effects on their health state. For instance, giving access to an outdoor area and pasture to growing pigs increases the incidence of osteochondrosis as compared to confined indoor housed pigs (for a review, see Etterlin et al., 2016). More generally, access to outdoors increases the risk of exposure to pathogens (parasites, pathogens external to the farm). Moving to outdoor systems in chickens, allows the expression of positive behaviours (Lay Jr et al., 2011) but increases the incidence of parasites like coccidiosis (Sossidou et al., 2015) and red lice (Knierim, 2006). These complex relationships between health and welfare, and production systems have been recently reviewed in the case of alternative pig (Delsart et al., 2020) and organic chicken farming (Holt,
2021), where outdoors access increased the risk of injury from predators and from flock mates, the risk and severity of diseases, and the mortality rate. There is therefore a possible level of negative interaction with welfare if biosecurity measures constrain farming practices (e.g. African swine fever, avian influenza, diseases affecting wildlife).

The transformation of breeding conditions, to better meet the animals' need for access to external and therefore more complex environments, must be designed in conjunction with a genetic approach to improve the animals' physiological adaptation to less controlled external living conditions (see below).

Apart from links discussed above, that all show that welfare and health usually vary in the same direction (bad welfare equal to bad health and probably vice versa), the question of possible tensions between them may be raised when thinking about the likely effects of profound changes in breeding practices. This raises research questions at the different scales at which these interactions, and potential tensions, are studied, from the animal to the livestock farming system in his territory. These research questions are presented below.

**Improving animal health and animal welfare in the transformation of farming activities**

There is already a considerable body of knowledge that can be mobilized to improve conjointly animal health and welfare of livestock. However, various questions arise at the scientific level. It will be necessary to not only deepen our knowledge of the interactions between health and welfare at the animal level but also to consider different levels of organization. Health and welfare interactions need to also be considered and quantified at the group, herd, farm, value chain and regional levels.
This includes going as far as considering impacts and questions involving the citizen and consumer. This is the overall framework of the research agenda that we propose below with the following themes:

- Interactions between animal health and animal welfare at the animal level.
- Interactions between animal health and animal welfare at the herd level
- Consideration of the expertise and well-being at work of breeders
- Interactions at the territory and production and value chain levels
- Research regarding the link between farming activities and society

**Interactions between animal health and animal welfare at the animal level**

As seen previously, different studies already explored positive interactions between health and welfare. However, this field of research remains fully open and among the various questions that can be addressed, we identify two that we consider as pushing at the boundaries of the scientific state-of-the-art. Does improving the state of animal welfare, in particular by facilitating the induction of prolonged or repeated positive emotions, impact their health, in terms of physiological balance and of their resistance to external aggressors, including pathogens? In addition, the role of the microbiota in the psycho-neuro-endocrine mechanisms, through the “gut-brain” axis, that link different aspects of welfare and health should be further explored.

Another important issue is to explore the trade-off between the physiological functions of production, reproduction and immunity, as well as to find the best possible equilibrium between efficiency of production, welfare and resilience of the animal (for
a review, see Rauw, 2008). Working on the physiological and genetic bases for these trade-offs could help identifying means of action. There are a few examples of such studies investigating trade-offs between production traits and immune function (e.g., Zerjal et al., 2021), but very few studies that include welfare as well. These questions concern both the short and longer stages over the entire animal's life, and a specific focus should be made in exploring the roles of the prenatal and juvenile periods, and transition phases in sub-adults or adults (weaning, gestation). Another dimension is to analyze the sensitivity of the animals to environmental conditions, such as their average harshness and variability.

**Interaction between animal health and animal welfare at the herd level**

Moving from the individual to the group of individuals, or to the farm, changes the scale and raises specific research questions. Research is needed on how do interactions between individuals, and between individuals and their environment, impact the health and welfare of the group. Key areas of focus are on positive emotions, microbiota flows, and exchanges of pathogens between animals and their environment. The context in which group livestock farming systems increasingly favour outdoors access to animals for promoting welfare, and the emergence of mixed species groups in extensive systems clearly pose questions. One paradigm that has gained traction in recent years is that the resilience of the livestock farm may be enhanced by encouraging a broader variability in the adaptive capacities of the individual animals in the group. If shown to be the case, this will be important especially in agro-ecological livestock farming systems where the group of animals will be more confronted by, and need to be able to cope with, environmental fluctuations.
If we consider the perspective of developing livestock farming systems that place animal health and welfare at the heart of the objectives, it will be necessary to do so whilst guaranteeing performance on all the pillars of sustainability (i.e. social, environmental and economic). This implies not only characterizing the synergies and tensions between health and welfare but also between these two components and the other performance parameters of the livestock farming system that contribute to its sustainability. The compromises that will have to be made in the choice of innovations in rearing practices can only be made in consultation with all the stakeholders. Given the ambition is to design systems that prioritize health and welfare, it will be necessary to know what is the cost of this choice on the other dimensions of performance and, thus, on the acceptability of these innovative systems. It will therefore be necessary to rely on open innovation methods such as living labs, which allow the co-conception of livestock farming systems taking into account the points of view and motivations of all stakeholders (including breeders, upstream and downstream industries, but also citizens' associations and consumers) considered as key players in the research and innovation process (e.g., Leminen, 2015) for general considerations on the living lab concept, and Chiron et al. (2022) for an example of participatory research project in rabbit production.

As highlighted in the 1.1 and 1.2 sections, a potentially powerful tool for measuring health status and welfare status is the on-farm technology that is being increasingly deployed as part of the general move towards precision livestock farming. These technologies can provide high-frequency objective measures on large numbers of animals (Højsgaard and Friggens, 2010). They already include measuring systems to
detect specific health events (e.g. onset of mastitis) and also use behavioural changes
to detect events such as onset of oestrus. For these tools to realise their full potential
for quantifying the interactions between health status and behavioural status the
following research developments are needed. These technologies are currently used
to detect specific events rather than to assess in a continuous way how health and
behavioural status evolve in response to different farm environments. Achieving the
latter requires that the algorithms used to process these data are ‘re-tuned’ to give a
more nuanced evaluation of health and behavioural status. Another scientific challenge
lies in the interpretation of technology-based behaviour data and animals’ emotions.
These technologies have been best developed in indoors housing systems (with easy
access to power supply and data transmission). Although there has been significant
progress, there remains a need to further develop these technologies for use in
outdoors, extensive, situations (Bocquier et al., 2014). Further research is also needed
to better make the link between measures made on individual animals and those made
on groups of animals. For example, camera-based measurements of groups can
reveal behaviours like dispersion of the group and average speed of movements (e.g.,
Sadoul et al., 2015) but it is not clear how to best combine group and individual
measures, or indeed when it is beneficial to do so. Advances on this would improve
the tools that could help breeders identify behavioural disorders that can be indicators
of disease or poor welfare conditions within the group.

The final area for development is not to do with these technologies per se but rather to
do with their interest and acceptance by breeders; the way they impact their work and
their mental workload with these new multiple data and the complexity of the
information to analyze, if they are adapted to the needs and skills of breeders and
reinforce their ability to observe the animals, or imply new learning and skills (Hostiou
et al., 2014). At present, there still remains an unwillingness to accept the measures coming from automated technologies amongst some experts in both fields. In our view, there is a need to provide the proofs that allow these researchers to accept that the benefits of having objective measures available on large-scale can often outweigh any perceived lack of specificity of said measures.

**Consideration of the expertise and the well-being at work of breeders**

Because of their daily work with, and dependence on animals, breeders have an expertise, an extended spectrum of skills, emotions, knowledge that should be considered with a real interest by scientists, farm advisors and veterinarians (O’Kane et al., 2017; Hansen and Østerås, 2019; Mahon et al., 2021) and more generally by society. Salmona (1985) pointed out the key role of breeders’ fear of diseases and strong emotional concern about animal pain and health in farming practice. In their job, care and disease with pain management are consubstantial; consequently, breeders must practically and emotionally cope with this reality. New ideas and practices emerge as breeders evolve in the way they define themselves as ‘good’ livestock rearers. Their insight skills in animal handling and management are also changing. Experimenting with practices, breeders develop new knowledge areas about animal health and behaviour, but their own interpretations of animal welfare and health are often poorly considered.

Consideration for animal health and rearing conditions vary according to a diversity and heterogeneity of farm types, productions and sizes. These range from mainstream agriculture to alternative-small-holding farms. Small-holders are considered by commercial farming as threats to the biosecurity because of a lack of disease-risk
awareness and bioinsecure practices. Going beyond those simplistic representations, Holloway (2019) insisted on the hybrid knowledge that small-holders acquire in the relationships with veterinarians and described how health management is bound up with practices of care. Opposing small-scale farming to commercial farming in terms of biosecurity is reductive as health and care practices are complex and heterogenous in farms (Holloway, 2019). It depends also on the way each farmer is considering how to be a “good farmer”, and a large diversity of farming styles have been identified in some studies (Commandeur, 2006). Moreover, breeders treat the health and welfare of different species, types and groupings of livestock in different ways, with differences between species, between animals of the same species, and between different life-stages or ages (Mahon et al., 2021). A large range of breeders, animal species, geographic situations, and local conditions create infinite combinations of animal-human relationships and ways of rearing. In that context, the challenge is to shift from an advisor-to-breeder knowledge transfer to a recognition and consideration of peer-to-peer systems and to encourage breeders’ exchanges. We make a plea here for setting up research projects on improving conjointly health and welfare of animals at the farm level that are co-constructed with breeders in order to benefit from their skills and expertise. One way to achieve this is to investigate farm situations and results with breeders that have already tested and made strong innovations in health and welfare on their farm, i.e., by tracking breeder’s innovations (Salembier et al., 2021). Another way to achieve this is to use the living labs conception process (see above).

If animal welfare is a component of sustainability (Buller et al., 2018), the breeders' well-being should be a legitimately associated goal, with a focus on the capability of breeders to create knowledge and competences and to innovate in the field of animal
welfare. This is an important aspect to be integrated under the banner of “One Welfare” (Buller et al., 2018). A key question is to what extent does an improvement in the health and welfare of their animals contribute to improving the well-being of breeders, their representation of work, personal and societal beliefs and satisfactions, and comfort at work. However, the contrary may also apply, that innovating on animal health and welfare can introduce new constraints for the breeders such as increased time or arduousness of the work. In parallel, it would be important to analyze what are the obstacles and drivers underlying changes to practices by breeders and transitions towards practices that are sustainable in terms of animal health and welfare; and what kind and extent of innovation are accomplished on the real farms. Porcher (2017) proposed to look in a new way at the relationships between farmers and animals, with the assumption that farm animals such as milking cows work. In this perspective, working conditions of both farmers and animals are considered, animals are respected as workers and the farmers rely on the intelligence of animals without exploiting them.

**Interactions at the territory and production and value chain levels**

With the emergence of societal concerns on animal health and welfare, breeders have appeared to initially be quite isolated with respect to providing answers and producing change in their farming practices (Quéméré and Le Neindre, 2013). Indeed, changes in regulations have often been the main driver for change in favour of animal welfare (Mounaix et al., 2013). Initially not involved in the debate (ethics, welfare), breeders and their organizations are fully engaged with it (Quéméré and Le Neindre, 2013). Indeed, co-operative organizations, as well as Standards Formulating Organizations (SFO), but also breeder groups initiatives, have been playing an important role in the
standards negotiations between breeders and retailers and in the implementation of welfare assessment tools like the Welfare Quality references (Aramyan et al., 2013; Bertrandias et al., 2021). Acknowledging that multi-stakeholder approaches are key to improve animal health and welfare, we then identify three main research topics at the regional and production sector levels that underlie the expected transition process towards livestock farming systems that promote both animal health and welfare.

Social, legal, economic and institutional processes involved

Changes in farming practices toward better health and welfare of animals must take account of all the diversity of farms in terms of their technical and economic orientations, the networks to which they belong (trading, strategic, technical, etc.) and any product differentiations that result with respect to their marketing. For the breeders, improving animal health and welfare should not penalize business returns. It could bring benefits, e.g. better animal productivity, reduction of drug use, and would thus allow breeders to gain the initiative in the animal welfare debate (Lawrence and Stott, 2009). However, improving animal health and welfare in livestock farms requires practices and/or system adaptations, new investments (Johan Lagerkvist et al., 2011), and maybe more workforce. These costs must usually be economically compensated by supports, as suggested for the European Common Agricultural Policy (Guyomard et al., 2023), or premiums and state product labelling. The health and welfare differentiation of the products, managed by the downstream part of the supply chain may affect consumer prices. There is a gap between the consumers’ stated willingness to pay more for animal health and welfare products and their real purchasing acts that remain price-oriented (Deblitz et al., 2021). Animal welfare labelling will inform
consumers and give the opportunity to make conscious consumer choices. This can have the consequence of them consuming fewer animal products (Deblitz et al., 2021).

This raises the question of the best productive and industrial strategies, the best public policies to set up to improve animal health and welfare while preserving the economy of the sectors, such as using market-led approaches or relying on supply-side solutions. The issues and questions raised here all relate to how to translate the challenges of emerging new paradigms such as the Eco-Health concept (“human-animal-ecosystem” interface) – for example by focusing on the example of antimicrobial resistance – into organizational processes for livestock rearing in different sectors and regions.

Technical, organizational innovations and coordination mechanisms

Various approaches can exist to push changes on animal health and welfare in the industry and in different regions. Research may be useful to analyze their efficacy or to support the process, among others different types of coordination (integration, “spot” markets, networks, etc.), the internationalization of agricultural and food markets, and different types of local cooperation between a variety of actors (agricultural or not). It can also be hypothesized that the multiplication of initiatives can potentially blur breeders and consumers perceptions, especially given the poor knowledge of citizens about farming methods (Cornish et al., 2016).

Changes to organisational systems will need to take into account: the diversity of systems co-existing in a same rural area (e.g. co-existence of indoor and outdoor systems); actor strategies (e.g. living with pathogens or eradicating them); the knowledge generated on health data (e.g. interactions with wild fauna); and technical
innovations (e.g. precision livestock farming) or organisational innovations (e.g. fab lab or networks of breeders). They must also be designed in the context of knowing what options can be developed for documenting or certifying the animal products, i.e. the monitoring and management of infectious diseases and welfare in the different sectors and regions. Likewise they will need to take into account what is the acceptability, by the downstream elements of the supply-chain including consumers, of “new” animal products from adapted livestock farming systems. Indeed, innovative, ground-breaking, systems that focus on health and welfare can be based on non-standard genetic types, produce animals that are heavier or lighter, fatter, older, altered seasonal production patterns. The consequences of these non-standardized animals on the processing of animal products need to be addressed. Finally, the feasibility and acceptability by field actors of new animal management philosophies, such as providing “retirement opportunities” for old animals, should be investigated.

Spatial distribution of farms, global conception of agricultural/food systems

The spatial distribution of livestock farming, the evolution of the herds' size and the emissions from the livestock industry, or, more globally, the question of the safe operating space for livestock production (Buckwell and Nadeu, 2018), must also be included in the debate (Deblitz et al., 2021), otherwise new disputes will arise again soon afterwards. These concern all the risks linked to the concentration of animals and industry: excessive effluents, impossibility of closing cycles in a circular economy, epizootics and other health risks. This evaluation can be carried out through stimulating the involvement of actors in different regions and sectors. It may involve developing the joint construction of organisational changes within certain sectors or regions so that
account can be taken of the health and welfare of animals throughout their lives. This includes issues such as the euthanizing animals of little economic value (male chicks, female ducklings, male kids, etc.) or alternatives to slaughtering animals for health reasons should also be considered. The potential interest of some practices that are almost non-existent today, such as “smallholders slaughters” managed by the breeders themselves, needs to be evaluated and this requires an environmental as well as an economic and social assessment. In a more holistic way, the structuring and functioning of our global food systems (from farm to fork) should be reexamined and democratically discussed (within the framework of citizens’ conferences, for instance). Topics such as the place, size and structure of livestock farming activities, the place of animal products in our diet, for instance, should be discussed. Various prospective studies could be mobilized to enlighten these reflections (Aubert et al., 2019).

Research regarding the link between farming activities and society

Combined consideration for societal concerns of health and welfare of animals

There is a growing societal concern for human health on the one hand, and animal welfare including farm animals in the other hand. They both gradually appear on policy agendas but these two trends, interrelated in this paper, are quite separated in society, science and political debates. Animal welfare concerns the way animals are farmed, transported, slaughtered and finally consumed (Buller and Roe, 2018). These topics are of increasing interest to many people in most parts of the world. Following non-governmental Organizations (NGOs) campaigns, the European Commission intends to propose to phase out and finally prohibit the use of cage systems, for all the species and categories mentioned in the End the Cage Age European Citizens’ Initiative
In parallel, dedicated structures and new regulations assigning to animals a status “as subjects”, and commercial standards promoting ethical market segmentation are emerging. These are collectively driving towards a movement of standardization and institutionalization of animal health and welfare.

Regarding health, and from a societal perspective, there are two public health threats. One major concern is the use of antimicrobials on livestock farms, with husbandry challenges associated with a drastic reduction in antimicrobial use in livestock to avoid resistance to antimicrobials used for humans (McEwen and Collignon, 2018). Another important health threat is the fact that emerging infectious diseases are dominated by zoonoses (Jones et al., 2008), which are diseases transmissible between animals and humans, directly or indirectly (e.g. food-borne, vector-borne zoonoses).

In our view, both challenges, animal health and welfare, could be better inter-related in an integrative perspective of improving farming sustainability (Buller et al., 2018), taking into account societal challenges, and providing better conditions for animal health and farming. However, this is no easy task as animal welfare and health also involve the entirety of the food chain, transcending the traditional divisions between production and consumption (Buller and Roe, 2018), with concern on ethical food and consumption. For instance, in 2016, the United Nations Committee on World Food Security Draft Recommendation has included an animal health and welfare article (Buller et al., 2018). This is in line with Haraway (2008) who proposed the statement of ‘response-ability’ both on farm and beyond into the supply chain. Here we propose to adopt an enlarged view that would include all stakeholders: breeders, processors, retailers, public institutions, consumers. In addition, to integrate animal welfare and
health issues, the panel of stakeholders should be further expanded to include scientists, veterinarians, civil society and NGOs, farm advisors, etc.

Dialogue between the various stakeholders and society

As seen previously, a discordance exists between citizens and breeders’ perceptions of animal health and welfare due to an increasing dissociation of citizens living in urban contexts far removed from farming practices reality (Vanhonacker et al., 2008). Physical health, an adequate and sufficient food and drinking water to meet animal needs are included in animal welfare, both by citizens and breeders. Citizens tend to include additional values: freedom to move and freedom to fulfil natural desires (Vanhonacker et al., 2008), that are integrated in the current definition of welfare. Also, citizens do not have a clear vision of animal health, apart from the fact that poor husbandry conditions and intensive farming increase the risk of disease and overuse of antimicrobials (Clark et al., 2016). Coming back to the idea of improving the knowledge of society and citizens on farming activities, as well as their image of livestock farming, there is a strong need for more intense and constructive exchanges between breeders, livestock industry and citizens. These different parties need to better know each other, to exchange their points of view, maybe to reconcile their midterm vision of what livestock farming could be ideally, and to work together to break up conflicts. Only a concerted path of this type will improve the vision of citizens about farming. In this respect, and as previously mentioned, the organization of citizens’ conventions (on livestock farming, and/or agricultural/food systems), including substantial training periods for participants, could be useful.

These challenges for the animal health and welfare sciences and for the humanities and social sciences are so vast that they cannot be met by individual disciplines, nor
by single or small groups of actors and stakeholders. We believe that, for specific research projects on cutting-edge farming-societal issues, transdisciplinarity research is required. Transdisciplinarity research addresses a complex, socially relevant issue, considers diverse perspectives and disciplinary approaches, links abstract and case-specific knowledge, and develops a common-good-oriented descriptive knowledge to address the issue (Pohl, 2011). A key point is recognizing the limits of science (and its experts) and respecting the expert knowledge of ‘lay people’ (i.e. citizens).

Perspectives and conclusion

To date, animal health and welfare have been treated as incidental issues in livestock farming systems. Taking into consideration these two components as a key and central point of the livestock farming systems has various and important implications. It questions the nature of the dominant production systems as well as the organization of the livestock sectors, through four complementary challenges (Figure 1).

Instead of correcting health and well-being damages, the approach is first to define what is considered good health and good welfare by stakeholders, and then to find practical and objective means of assessing these two components (Figure 1A). Health and welfare are partly linked given their definitions but also because they have positive effects on each other. The mechanisms involved need further investigation. In addition, the desire to improve both raises specific questions because they sometimes interact negatively and considering them together may lead to trade-offs that need to be explored throughout the animal’s life (Figure 1B).
Transforming livestock farming systems to improve animal welfare and health also raises a number of questions about: the design of livestock farming systems to ensure good health and welfare, the economic profitability of these improved systems, the well-being of breeders at work, and the adaptation of the livestock sectors to incorporate these innovations (Figure 1C). Work is needed to study the levers for action and to support these approaches, including the role of public policies in facilitating the transformations.

Finally, the evolution of livestock farming systems to improve animal health and welfare needs to be considered in the context of a broader vision of livestock production, with a view to multi-performance and sustainability (Figure 1D). This point relates notably to the acceptability of animal farming by the society, and its place in a one health and one welfare perspective. Working with citizen and consumers on the co-construction of a common vision of acceptable and environmentally friendly livestock farming is an important and urgent task.

Some of the research questions raised in this paper refer to biology, for example psycho-neuro-endocrinal mechanisms linking positive mental state and health, and many others relate to animal sciences. However, some of them undeniably involve cultural aspects that can differ from place to place. These include options available in some countries that might not be applicable in others. Part of the questioning presented here calls for regionally-focused research, that can take place in different cultural contexts. It also pleads for an interdisciplinary approach involving Human sciences and economics in close collaboration with animal and veterinary sciences, and for transdisciplinary research involving all stakeholders.
Figure 1. Challenges to address in moving livestock farming towards greater consideration of animal health and welfare.

A. Better assessment of animal health and welfare
B. Understanding the positive and negative interactions between animal health and welfare (synergies and trade-off)
C. Co-design of innovative livestock farming systems improving animal health and welfare
D. Multiperformance and sustainability of livestock farming systems improving animal health and welfare
Ethics approval

This work was conducted without carrying any experiment on animals.

Data and model availability statement

This work was not grounded on data and model.

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Declaration of interest

The authors declare that they have no competing interests.

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